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CALPIONELLID AND NANNOCONID STRATIGRAPHY AND MICROFACIES OF LIMESTONES AT THE TITHONIAN–BERRIASIAN BOUNDARY IN THE SIERRA DEL INFIERNO (WESTERN CUBA)

Andrzej PSZCZÓŁKOWSKI[1], Dora GARCÍA DELGADO[2] & Santa GIL GONZÁLEZ[3]

[1] *Institute of Geological Sciences, Polish Academy of Sciences, ul. Twarda 51/55, PL-00-818 Warszawa, Poland, apszczol@twarda.pan.pl*
[2] *Instituto de Geología y Paleontología, Vía Blanca y Prolongación de Calzada de Güines, S/N, San Miguel del Padrón, Ciudad de la Habana, Codigo Postal 11000, La Habana, Cuba, dora@igp.minbas.cu*
[3] *Centro de Investigaciones del Petróleo, Washington 169, Cerro, Habana 12000, Cuba, santa@ceinpet.cupet.cu*

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Abstract: The radiolarian and calpionellid microfacies are characteristic for the latest Tithonian–Early Berriasian limestones of the Guasasa Formation in the Sierra del Infierno, western Cuba. The limestones of the uppermost part of the El Americano Member belong to the Late Tithonian *Crassicollaria intermedia* Subzone, *Crassicollaria* Standard Zone, and to the basal part of the Early Berriasian *Calpionella alpina* Subzone. The lower part of the Tumbadero Member is assigned to the *C. alpina* Subzone of the *Calpionella* Standard Zone. A heteromorph ammonite assemblage (*Protancyloceras-Vinalesites*) crosses the *Crassicollaria/Calpionella* Zones boundary. The studied limestones belong to three nannoconid assemblages of latest Tithonian–Early Berriasian age assigned to *Nannoconus wintereri* Subzone, *N. steinmannii minor* Subzone and *N. steinmannii steinmannii* Zone. Radiolarian taxa identified in thin sections are consistent with the lower part of D2 radiolarian zone from Western Tethys. The investigated deposits have been probably accumulated in the dysaerobic zone. At the Tithonian–Berriasian (J/K) boundary, dysaerobic to anaerobic conditions could be widespread in the deeper waters of the northwestern Proto-Caribbean basin.

Key words: calpionellids, *Nannoconus*, Radiolaria, microfacies, latest Tithonian–Early Berriasian western Cuba.

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INTRODUCTION

Since Brönnimann's (1954) pioneering contribution, calpionellids of the Tithonian–Valanginian limestones in Cuba have been studied by various authors. The Tithonian–Berriasian boundary was also designated in some papers, but detailed microfossil stratigraphy of well-documented Cuban sections still appears to be uncommon in published works. However, the west Cuban sections are important for palaeogeographic reconstructions and palaeoceanography of the Proto-Caribbean basin during Jurassic and Cretaceous times (Pszczółkowski, 1987, 1999; Pszczółkowski & Myczyński, 2004).

Two sections of the latest Tithonian–Early Berriasian limestones were sampled in the Sierra del Infierno, which is a part of the Sierra de los Organos belt in the Pinar del Río Province (western Cuba). Our principal aims were as follows: (1) to document the position of the Tithonian–Berriasian boundary in the framework of the local lithostratigraphic subdivision, and (2) to characterize microfacies composition of the latest Tithonian and Early Berriasian limestones. We also present some observations concerning sedimentary conditions that existed in the northwestern part of the Proto-Caribbean basin at the Jurassic–Cretaceous boundary.

PREVIOUS WORK

Kreisel and Furrazola-Bermúdez (1971) recognised the presence of the *Crassicollaria* and *Calpionella* zones in western Cuba. Furrazola-Bermúdez and Kreisel (1973) identified diverse calpionellid species and concluded that their results do not permit to precisely establish the Jurassic–Cretaceous boundary. Pop (1976) presented stratigraphic distribution of the calpionellids in three sections of the

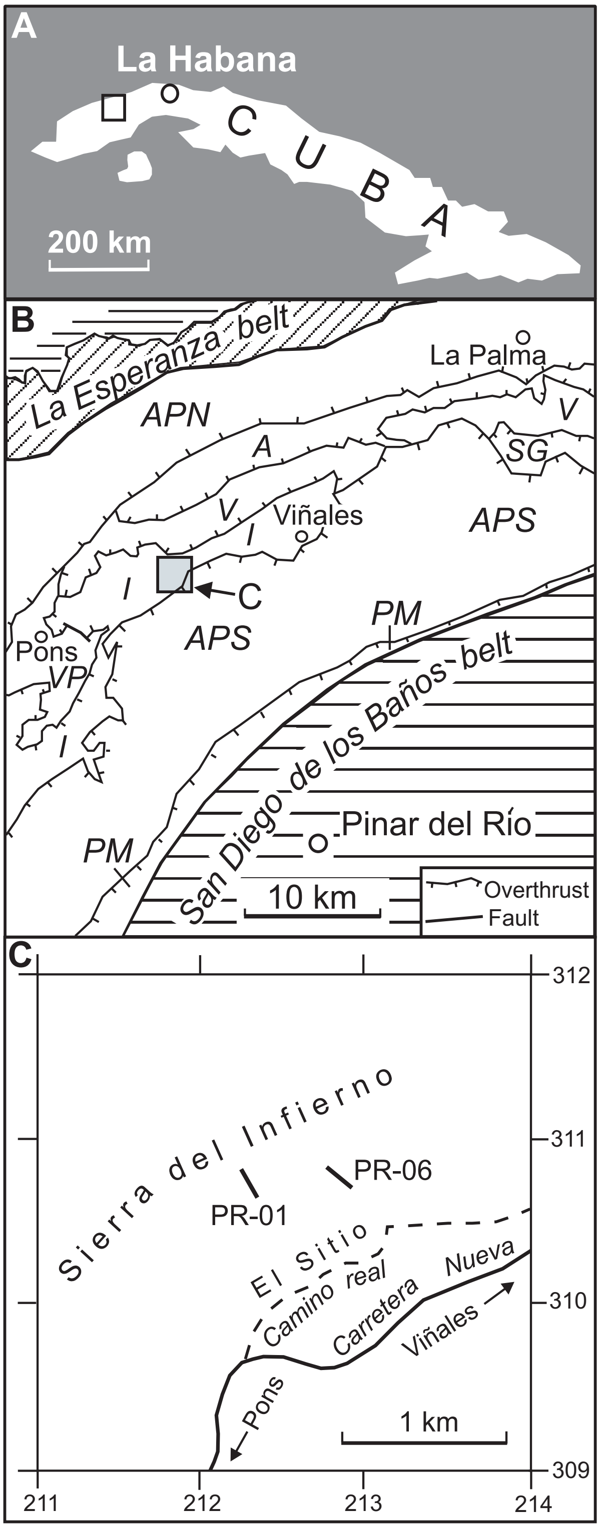

Fig. 1. A – Location of the studied sections in Cuba. **B** – Tectonic scheme of the area situated in the Sierra de los Organos between Pons and La Palma (after Pszczółkowski, 1978; modified). Tectonic units of the Sierra de los Organos belt (cf. Piotrowska, 1978): *PM* – Cangre (Pino Solo and Mestanza subunits), *APS* – Alturas de Pizarras del Sur, *VP* – Valle de Pons; *I* – Infierno, *SG* – Sierra la Güira, *V* – Viñales, *A* – Ancón. Tectonic units of the Sierra del Rosario belt (generalized): *APN* – Alturas de Pizarras del Norte. **C** – Location map of the PR-01 and PR-06 sections in the Sierra del Infierno, west of Viñales (topographic coordinates refer to the Minas de Matahambre sheet of the 1 : 50,000 map)

Table 1

Subdivision of the Guasasa Formation in the Sierra de los Organos (western Cuba), after Pszczółkowski (1978, 1999)

Age	Formation	Members
Early Valanginian	Guasasa	Tumbitas
Berriasian		Tumbitas / Tumbadero
Tithonian		El Americano
Kimmeridgian		San Vicente
Late Oxfordian		San Vicente

Sierra de los Organos. In the San Vicente and Hacienda El Americano sections, he has identified the *Crassicollaria* and *Calpionella* zones, although the Tithonian–Berriasian boundary has been indicated within the *Calpionella* Zone (Pop, 1976). Pszczółkowski (1978) located this boundary at the base of the *Calpionella* Standard Zone in the Sierra de los Organos and the Sierra del Rosario belts. In the former belt, Myczyński and Pszczółkowski (1990) correlated the Tithonian ammonite and microfossil zones and maintained the Tithonian–Berriasian boundary at the base of the *Calpionella* Standard Zone. In his unpublished work, Fernández-Carmona (1998) reported on the Jurassic–Cretaceous boundary from the Hacienda El Americano section. According to Fernández-Carmona (1998), this boundary located in the uppermost part of the El Americano Member is characterized by a gradual transition in the calpionellid assemblages. Pszczółkowski and Myczyński (2004), partly after their earlier papers, accepted the earliest Berriasian age of the topmost limestones of the El Americano Member in some sections of the Sierra de los Organos.

GEOLOGICAL SETTING AND LITHOSTRATIGRAPHY

The studied sections are situated in the Sierra de los Organos, 10 km west of Viñales, on the south-facing slope of the Sierra del Infierno (Fig. 1B, C). Two sections (PR-01 and PR-06), 500 m apart, are located upslope above the old road (Camino Real) at the El Sitio locality. They occur in the Infierno tectonic unit, north of the Alturas de Pizarras

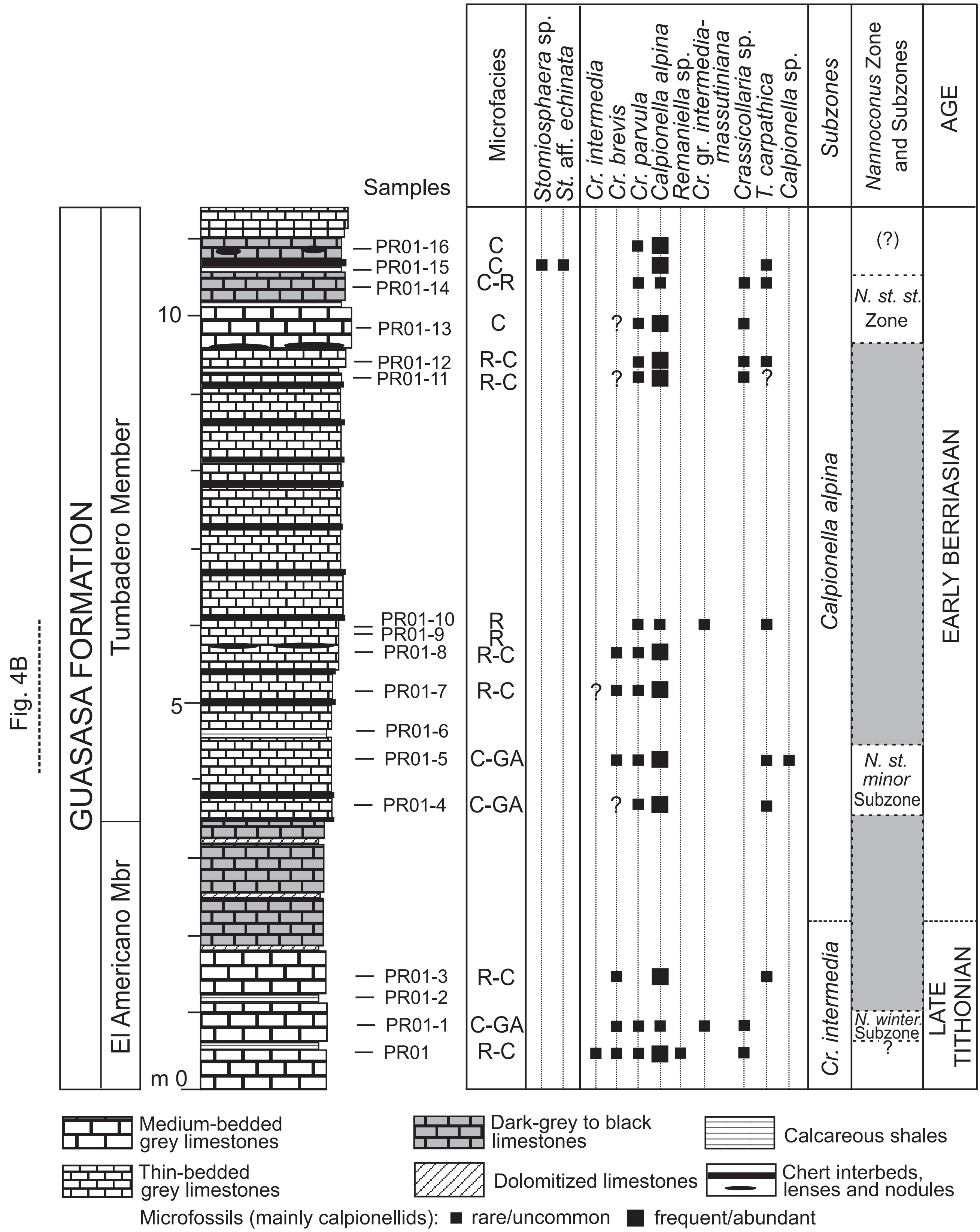

Fig. 2. PR-01 section in the Sierra del Infierno (Sierra de los Organos belt, western Cuba): lithostratigraphy, microfacies, calpionellids and calcareous dinocysts. Abbreviations: C – calpionellid microfacies, GA – *Globochaete* microfacies, R – radiolarian microfacies (and their combinations); *N. st. st. – Nannoconus steinmannii steinmannii, N. st. minor – Nannoconus steinmannii minor*, *N. winter. – Nannoconus wintereri*; the shaded bands denote intervals of uncertainty concerning location of the zonal boundaries. *N. steinmannii steinmannii* Zone and *N. steinmannii minor* Subzone were distinguished by Bralower *et al*. (1989), and the *N. wintereri* Subzone was suggested by Tavera *et al*. (1994) as NJK-c Subzone

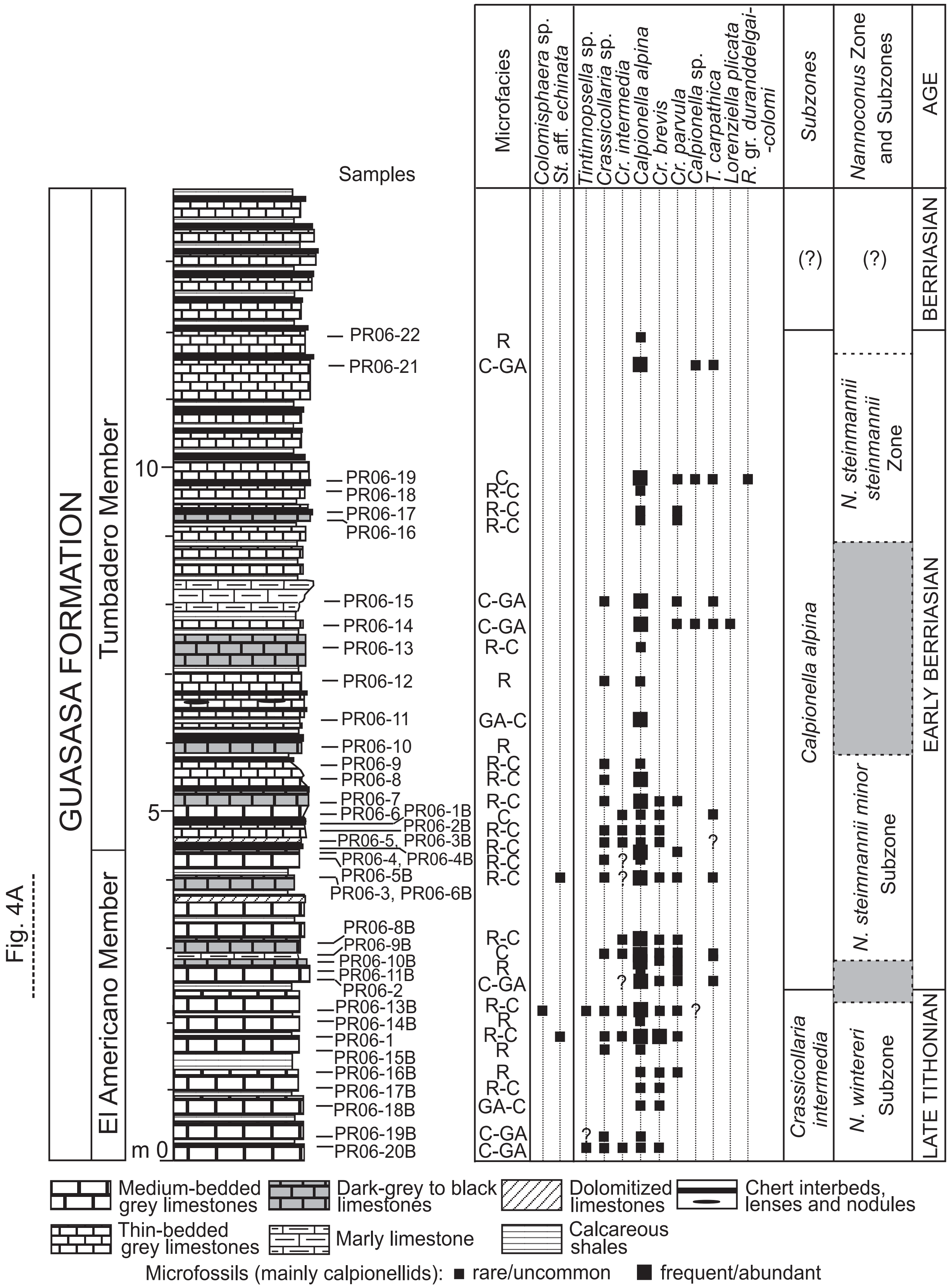

Fig. 3. PR-06 section in the Sierra del Infierno (Sierra de los Organos belt, western Cuba): lithostratigraphy, microfacies, calpionellids and calcareous dinocysts. Microfacies abbreviations and other explanations as in Fig. 2

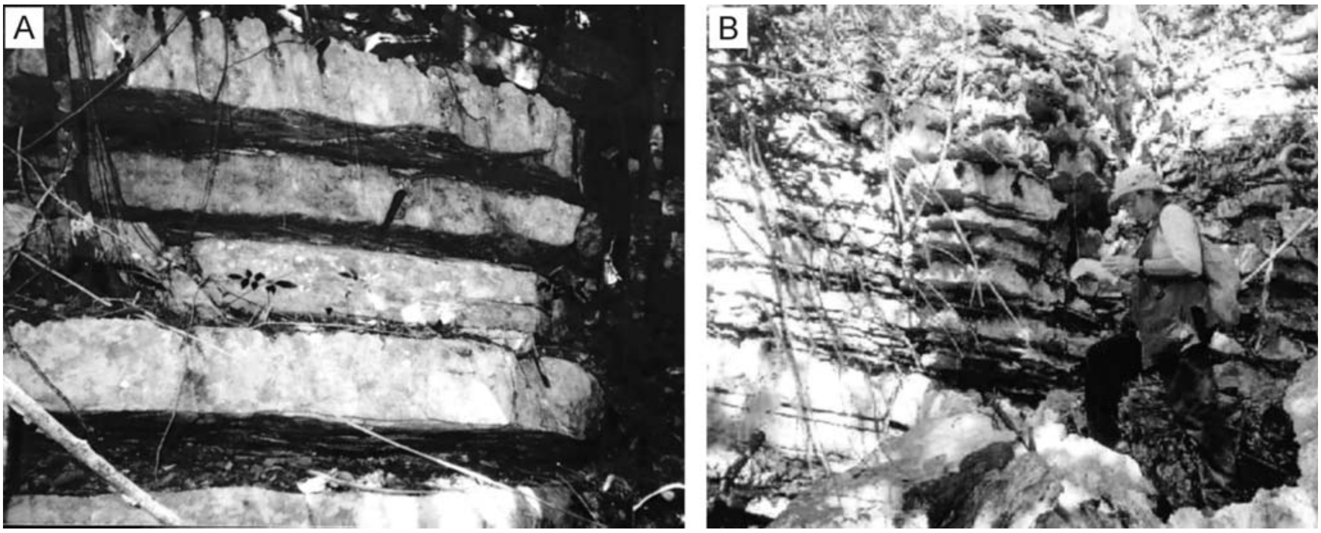

Fig. 4. **A** – Limestones of the uppermost part of the El Americano Member in the PR-06 section, Sierra del Infierno. **B** – Limestones with thin chert interbeds in the lower part of the Tumbadero Member; PR-01 section, Sierra del Infierno

del Sur overthrust (Fig. 1). The lithostratigraphic scheme of the Jurassic and Early Cretaceous rocks in the Sierra de los Organos belt was elaborated by Hatten (1957), partly modified by Herrera (1961) and adapted by Pszczółkowski (1978, 1999) with some changes.

The sampled interval comprises the uppermost part of the El Americano Member (Houša and Nuez, 1972) and lower part of the Tumbadero Member (Herrera, 1961) of the Guasasa Formation (Table 1, Figs 2, 3). The El Americano Member consists of bedded dark-grey to black limestones (Fig. 4A), sometimes dolomitized, 20 to 45 m thick. These limestones, mainly Tithonian in age, contain common ammonites in the lower and middle parts of the Member (Myczyński, 1989). Towards the top of the El Americano Member, ammonites became less frequent to rare in some sections. The transition to the overlying Tumbadero Member (Herrera, 1961) is gradational. This unit, up to 50 m thick, is Berriasian in age (Table 1). It comprises thin-bedded limestones with interbeds of black chert (Fig. 4B), frequently laminated (Pszczółkowski, 1978).

DESCRIPTION OF STUDIED SECTIONS

PR-01 SECTION

The PR-01 section (Fig. 2) comprises the limestones of the El Americano Member, 3.5 m thick, and the limestones and cherts of the Tumbadero Mbr (Fig. 4B), 7.8 m thick. The section begins with thick limestone beds (30–70 cm), weathering violet or brown, with thin interbeds of dark-grey shaly limestone to calcareous shale. The overlying limestones are dark-grey, weathering brown or violet. These limestone beds form the topmost part of the El Americano Member in the studied section. The transition to the Tumbadero Member is gradational; this unit begins with the black chert 2 cm thick (Fig. 2). Higher up in the section, grey micritic limestones in places mottled and partly silicified occur in the interval of about 2 m thick. The next bundle of strata 3.3 m thick consists of grey to greyish-brown medium-bedded limestones with black chert interbeds. Relatively thicker greyish-brown limestone beds appear in the overlying interval about 1 m thick, followed by dark-grey to black limestones occasionaly laminated, with thin chert interbeds. The described lower part of the Tumbadero Member is capped by a grey limestone (0.3 m). The remaining strata of the Tumbadero Member, about 32 m thick, exposed in the Sierra del Infierno, have not been sampled within the present study.

PR-06 SECTION

The PR-06 section (Fig. 3) is situated about 500 m east of the above-described one.

In this section, the sampled interval comprises the uppermost part of the El Americano Member (4.5 m) and lower part of the Tumbadero Member (about 9.4 m). Grey to black limestones of the former member occur in beds 10–30 cm in thickness (Fig. 4A). Interbeds of hard, laminated calcareous shales and marly limestones appear between the limestone beds, which are also occasionally laminated. The boundary between the El Americano and Tumbadero members is placed at the base of the first black chert interbed in the limestone succession. The Tumbadero Member consists of grey to black limestones with calcareous shale and black chert interbeds, lenses and nodules. In the topmost part of the section (above the sample PR06-21, Fig. 3) chert interbeds are thicker and always appear together with the calcareous shale. No macrofossils have been found during sampling. Two partly overlapping sets of samples were collected in this section. Samples with letter B were taken to extend downward the sampled interval of the El Americano Member.

MICROFACIES

In the uppermost El Americano Member limestones, the recognized microfacies types are as follows: a calpionellid biomicrite (Fig. 5A), sometimes with subordinate *Globochaete alpina* Lombard, *Globochaete* biomicrite with occasional calpionellids, and radiolarian biomicrite with (or without) calpionellids (Fig. 6A). In the Sierra de los Organos belt, radiolarians appeared in the Late Tithonian (Myczyński & Pszczółkowski, 1990). In the sections under study, the radiolarian and radiolarian-calpionellid microfacies are important in the limestones of the uppermost part of El Americano Member (Fig. 3). Also, these microfacies types predominate in the limestones of the lower part of the Tumbadero Member. Nevertheless, calpionellid and calpionellid-*Globochaete* biomicrites still persist in these intervals as subordinate microfacies types. Recurring appearance of the calpionellid-*Globochaete* microfacies between the radiolarian biomicrites is a characteristic feature of the studied latest Tithonian–Early Berriasian limestones. The main microfacies types of these limestones may be compared with Flügel's (1982) Standard Microfacies Type 3 (pelagic mudstone and wackestone). Pelmicrosparite (Fig. 5B) and laminated biomicrite (Fig. 6B) were also observed in the investigated Early Berriasian limestones. The pelmicrosparite contains fecal pellets of ellipsoidal outline, which differ from the *Favreina*-like coprolites described from the pre-Titho-

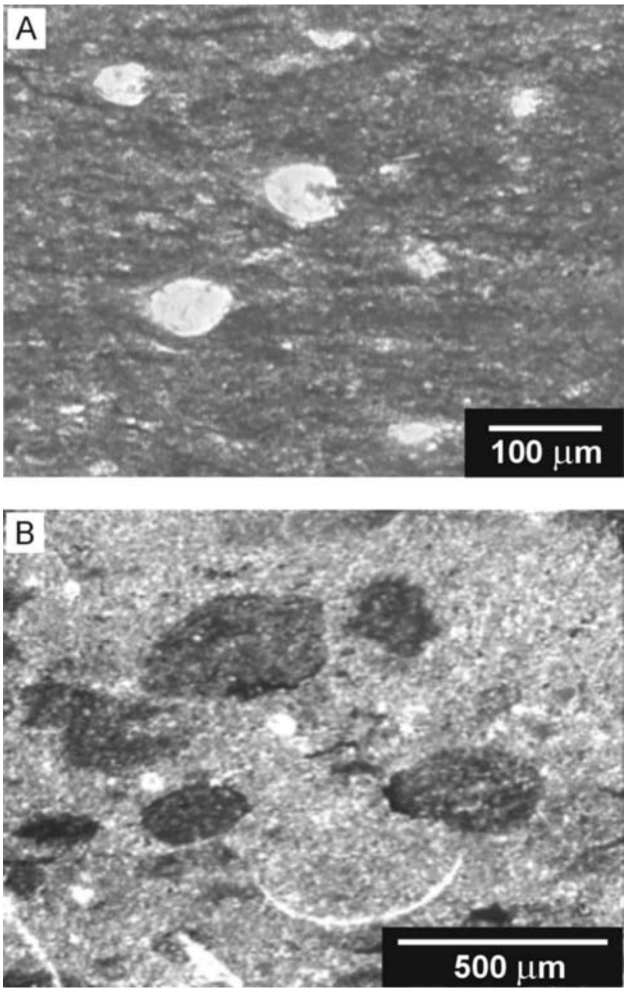

Fig. 5. **A** – Calpionellid biomicrite, sample PR06-9B (earliest Berriasian). **B** – Pelmicrosparite with ellipsoidal coprolites and some tiny bioclasts, sample PR01-16 (Early Berriasian)

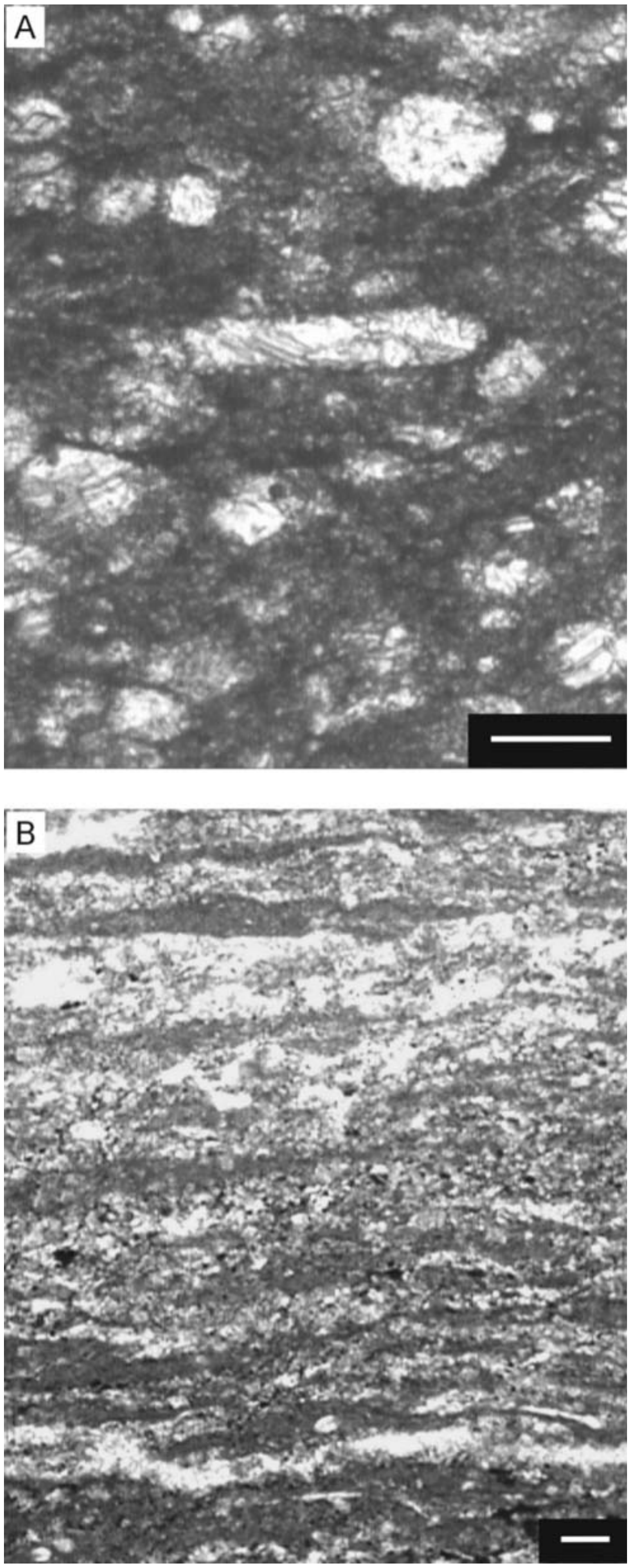

Fig. 6. **A** – Radiolarian biomicrite; sample PR06-1 (latest Tithonian). **B** – Laminated biomicrite/microsparite with occasional calpionellids in dark laminae; sample PR01-15 (Early Berriasian)

Table 2

Relative frequency of calpionellid taxa in eight samples of the latest Tithonian–Early Berriasian limestones from the Sierra del Infierno (western Cuba)

Sample (thin section)	Relative frequency of calpionellid taxa (%)										Number of identified specimens
	C. alpina	*C.* sp.	*Cr. inter.*	*Cr.* gr. *interm .-massut.*	*R.* gr. *d.-c.*	*Rema-niella* sp.	*Cr. brevis*	*Cr. parv.*	*Cr.* sp.	*T. carpathica*	
PR06-19	79	1.7	-	-	1.7	-	-	10	0.9	6.7	119
PR01-13	79.9	-	-	-	-	-	1.5(?)	8.2	10.4	-	134
PR06-8B	95.6	-	0.4	-	-	-	1	3	-	-	225
PR06-9B	88.4	-	0.2	-	-	-	1	10	0.2	0.2	290
PR06-10B	93	-	-	-	-	-	2	5	-	-	118
PR06-2	97.5	-	-	0.5	-	-	1	0.5	-	0.5	237
PR06-1	65.8	-	1	-	-	-	17	8.6	7.6	-	105
PR01	68	-	3.9	-	-	1	4.8	3.9	16.5	-	103

C = *Calpionella*; *Cr. interm.* = *Crassicollaria intermedia*; *Cr.* gr. *interm.-massut.* = *Crassicollaria* gr. *intermedia-massutiniana*; *R.* gr. *d.-c.* = *Remaniella* gr. *duranddelgai-colomi*

nian Late Jurassic limestones, also in the Sierra de los Organos belt (Seiglie, 1961; Pszczółkowski, 1978).

CALPIONELLID STRATIGRAPHY

The frequency of calpionellids in studied thin sections is highly variable, from scarce to abundant. These microfossils are poorly preserved in the investigated samples. This is a common feature of calpionellids occurring in the Late Tithonian and Berriasian limestones of the Sierra de los Organos belt where, according to Pop (1976), calpionellids are common or abundant but intensely recrystallized. As a rule, the radiolarian biomicrites contain poor calpionellid assemblages. This state of preservation and fluctuations in frequency of calpionellids between the samples do not allow to characterize calpionellid assemblages by more than two categories of relative frequency in the majority of samples reflecting a relative frequency of the identified taxa (Figs 2, 3). These categories of calpionellid occurrences were estimated also in thin sections containing less than 100 determined specimens. Only in eight thin sections the number of identified calpionellids did exceed 100 specimens (Tab. 2).

Crassicollaria intermedia Subzone of the *Crassicollaria* Standard Zone

The limestones of the El Americano Member that belong to the *Crassicollaria intermedia* Subzone of the *Crassicollaria* Standard Zone (Remane *et al*., 1986) are 2.7 m and about 2.5 m thick, respectively (Figs 2, 3). The calpionellid assemblage occurring in these limestones contains *Crassicollaria brevis* Remane (Fig. 7D, F), *Cr. intermedia* (Durand-Delga) (Fig. 7E), *Cr. parvula* Remane, *Tintinnopsella* sp., and *Calpionella alpina* Lorenz. The upper boundary of this subzone is indicated between samples PR06-13B and PR06-2 (Fig. 3), because of a marked prevalence of *Calpionella alpina* in the calpionellid assemblage in the latter sample (Tab. 2). In the PR-01 section (Fig. 2), the upper boundary of the *Intermedia* Subzone is located below the PR01-4 sample, somewhat arbitrarily within the limestone interval 2.2 m thick (not sampled). Thus in the considered sections, the El Americano/Tumbadero boundary occurs clearly above the boundary of the *Crassicollaria* and *Calpionella* zones recognized on the basis of the *Calpionella alpina* "explosion" (Allemann *et al*., 1971; Remane, 1986). This is the Tithonian–Berriasian boundary still valid for many authors, especially those working in the calpionellid stratigraphy (e.g., Remane *et al*., 1986; Pop, 1994; Houša *et al*., 1999, 2004). Nevertheless, in the Puerto Escaño section (southern Spain) the base of the ammonite *Jacobi* Zone was correlated with the upper part of the *Intermedia* Subzone (Tavera *et al*., 1994). As the ammonites characteristic for the Tethyan *Jacobi* Zone have not been found in west Cuban sections, we decided that it would be premature to place the Tithonian–Berriasian boundary within the *Crassicollaria intermedia* Subzone (*sensu* Remane *et al*., 1986) in the studied sections.

Calpionella alpina Subzone of the *Calpionella* Standard Zone

In sample PR06-2, relative frequency of *C. alpina* reaches 97.5% with only low percentages of crassicollarians and *Tintinnopsella carpathica* (Murgeanu & Filipescu). High relative frequency of *Calpionella alpina* represented by a small, sphaerical form (Fig. 7A) strongly suggests that this is the "explosion" of the mentioned taxon that defines

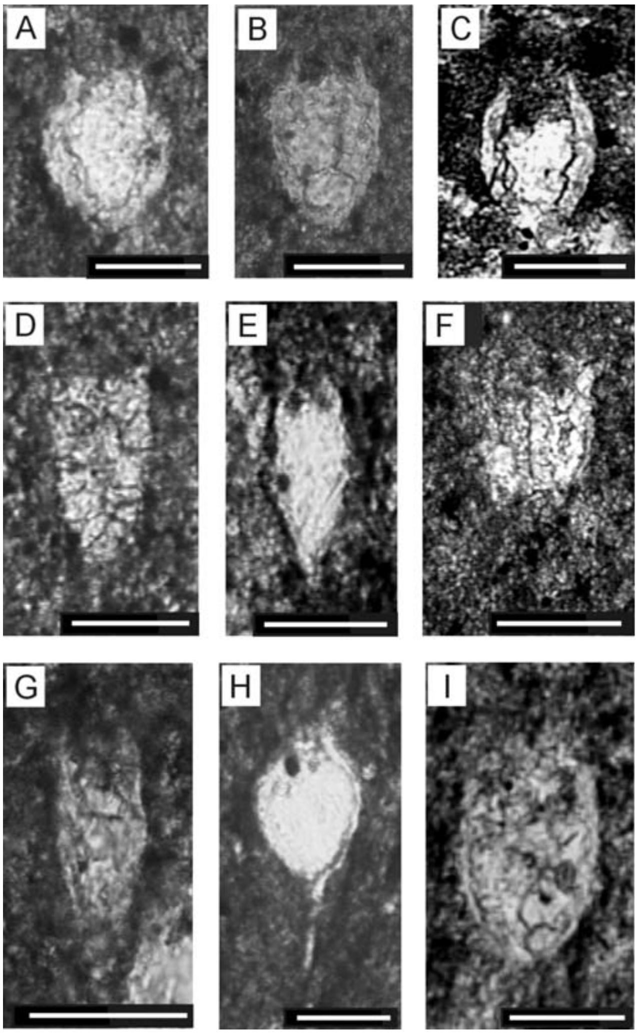

Fig. 7. Calpionellids from the Sierra del Infierno sections: **A–C** – *Calpionella alpina* Lorenz, A – sample PR06-10B, earliest Berriasian; B – sample PR06-2, earliest Berriasian; C – sample PR01-15, Early Berriasian; **D** – *Crassicollaria brevis* Remane, sample PR01-1, latest Tithonian; **E** – *Crassicollaria intermedia* (Durand-Delga), sample PR06-1, latest Tithonian; **F** – *Crassicollaria brevis* Remane, sample PR01-3, latest Tithonian; **G** – *Lorenziella plicata* Remane, sample PR06-14, Early Berriasian; **H** – *Tintinnopsella carpathica* (Murgeanu & Filipescu), sample PR06-19, Early Berriasian; **I** – *Remaniella* gr. *duranddelgai-colomi*, sample PR06-19, Early Berriasian. Scale bar = 50 µm

the base of the *Calpionella* Standard Zone (Remane, 1985, 1986, 1997). However, few elongated specimens of *C. alpina* were also observed (Fig. 7B). Rare specimens of *Crassicollaria brevis* and *Cr.* gr. *intermedia-massutiniana* (assigned to *Cr. intermedia*? in Fig. 3) are still present in this assemblage. Samples PR06-8B and 9B contain *Cr. brevis*, *Cr. parvula* and scarce specimens of *Cr. intermedia*. The taxa *Crassicollaria brevis* Remane, *Cr. intermedia* (Durand-Delga) and *Cr*. gr. *intermedia-massutiniana* persist in the samples located 2.5 to 3.5 m above the base of the *C. alpina* Standard Zone established in the studied sections. Similar occurrences were registered earlier in the San Vicente, Ancon Valley, and Hacienda El Americano sections of the Sierra de los Organos (Pop, 1976, 1986). It

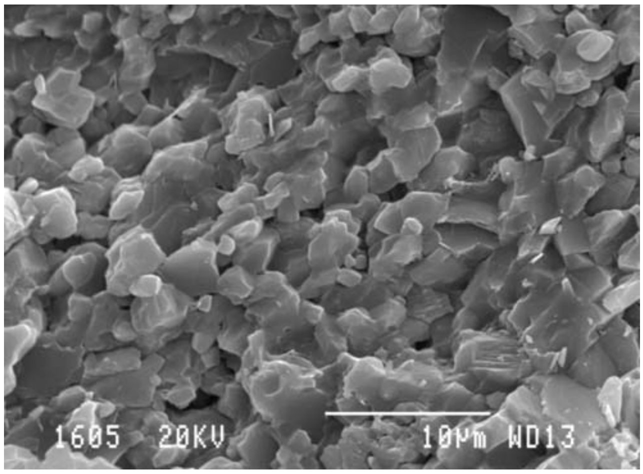

Fig. 8. SEM micrograph of partly recrystallized mictitic limestone containing rare specimens of *Nannoconus steinmannii* Kamptner subsp. *steinmannii* Deres & Achéritéguy (at right)

seems that in this belt the *Calpionella alpina* "explosion" was not strictly coeval with the final disappearance of taxa typical of the Late Tithonian (*Cr. intermedia*, *Cr.* gr. *intermedia-massutiniana* and *Cr. brevis*). According to Fernández-Carmona (1998), the J/K boundary in Cuba is characterized by a gradual transition in the calpionellid assemblages. Occurrence of "Late Tithonian" crassicollarians in the earliest Berriasian was documented also in a few European sections (Pop, 1987; Tavera *et al*., 1994). Olóriz *et al*. (1995) mention a presence of rare specimens of *Cr. brevis* in the Early Berriasian *Alpina* Subzone of Mallorca.

Typical Early Berriasian calpionellid assemblage, without crassicollarians characteristic for the Late Tithonian, occurs in the lowermost Tumbadero Member, about 3 m above the *Crassicollaria/Calpionella* zones boundary (Fig. 3). The samples from the lower part of the Tumbadero Member (an interval about 8 to 9.5 m thick) belong to the Early Berriasian *C. alpina* Subzone of the *Calpionella* Standard Zone. Representatives of *Calpionella alpina* (small variety; Fig. 7A, C), *Crassicollaria parvula* Remane and *Tintinnopsella carpathica* (Murgeanu & Filipescu) (Fig. 7H) are the main components of the Early Berriasian assemblage. Rare finds of *Lorenziella plicata* Remane (Fig. 7G), *Remaniella* gr. *duranddelgai-colomi* (Fig. 7I) and *Calpionella* sp. are also reported herein (Fig. 3).

NANNOCONIDS

Scanning Electron Microscope study revealed the presence of nannoconids in 17 samples (Tab. 3). In a number of samples nannoconids are scarce to rare (Fig. 8) or too poorly preserved to be determined. Samples PR01-1 and PR06-1 taken from the uppermost El Americano Member limestones, latest Tithonian in age yielded *Nannoconus wintereri* Bralower & Thierstein (Fig. 9C), and *N.* cf. *wintereri* (Fig. 9D) as the principal component of nannoconid assemblage. Specimen of *Nannoconus* sp. aff. *N. infans* Bralower (Fig. 9A) is slightly larger than typical *N. infans* (Fig. 9G; cf. Bralower *et al*., 1989). Taxon *N. wintereri* occurs also in

Table 3

Nannoconus assemblages from the latest Tithonian–Early Berriasian limestones in the Sierra del Infierno (western Cuba)

Samples from sections PR-01 and PR-06	Taxa identified	*Nannoconus* zone/subzone	*Calpionellid subzone*	Age
PR06-21	*N.* aff. *infans* *N. kamptneri kamptneri* *N. steinmannii minor* *N. steinmannii steinmannii*	*Nannoconus steinmannii steinmannii*	*C. alpina*	Early Berriasian
PR06-18	*N. kamptneri kamptneri* *N. steinmannii minor* *N. steinmannii steinmannii*			
PR01-14	*N. steinmannii minor* *N. steinmannii steinmannii*			
PR01-13	*N. infans* *N. kamptneri kamptneri* *N. kamptneri minor* *N. steinmannii steinmannii*			
PR06-16	*N. kamptneri kamptneri* *N. steinmannii minor* *N. steinmannii steinmannii*			
PR06-9	*N. globulus globulus* *N. kamptneri minor* *N. wintereri* *N.* gr. *colomii-steinmannii*	*N. steinmannii minor* (?)		
PR06-3B	*N. steinmannii minor*	*N. steinmannii minor*		
PR06-3	*N. kamptneri kamptneri* *N.* cf. *kamptneri minor* *N. steinmannii minor* *N.* sp. aff. *N. infans* *N.* gr. *wintereri-kamptneri*			
PR06-10B	*N. kamptneri kamptneri* *N. kamptneri minor* *N. steinmannii minor*			earliest Berriasian
PR01-5	*N. steinmannii minor*			
PR01-4	*N. steinmannii minor* *N. wintereri* *N.* gr. *wintereri-kamptneri*			
PR06-13B	*N. infans* *N. wintereri*	*Nannoconus wintereri*	*Cr. intermedia*	latest Tithonian
PR06-1	*N. globulus globulus* *N. wintereri* *N.* cf. *wintereri*			
PR06-15B	*N. infans* *N. wintereri*			
PR06-16B	*N. infans* *N. wintereri*			
PR01-1	*N.* sp. aff. *N. infans* *N.* cf. *wintereri*	*Nannoconus wintereri* (?)		
PR06-20B	*N. wintereri* *N.* cf. *wintereri*	*Nannoconus wintereri*		

sample PR01-4, earliest Berriasian in age (Tab. 3). Sample PR06-3 contains *N. steinmannii* Kamptner subsp. *minor* Deres & Achéritéguy (Fig. 9E), *N. kamptneri* Brönnimann subsp. *minor* Bralower and *N. kamptneri kamptneri* emended by Bralower, Monechi & Thierstein. The taxa *N. steinmannii* Kamptner subsp. *minor* Deres & Achéritéguy (Fig. 9B) and *N. steinmannii* Kamptner subsp. *steinmannii* Deres & Achéritéguy (Fig. 9F) were found in samples PR01-13, PR01-14, PR06-16, PR06-18 and PR06-21 (Tab. 3). *Nannoconus globulus globulu*s Bralower, Monechi & Thierstein occurs in the sample PR06-9 (Fig. 9H; Tab. 3)

In southern Spain, Tavera *et al*. (1994) subdivided the NJK Zone of Bralower *et al.* (1989) into NJKa-d subzones based on the first appearances of *Nannoconus infans*, *N. wintereri* and *N. steinmannii* Kamptner subsp. *minor*. The Late Tithonian NJK-b Subzone begins with *N. infans* appearance and NJK-c Subzone with *N. wintereri* first occurrence (Tavera *et al*., 1994). The latter subzone is placed across the Tithonian–Berriasian boundary, as defined by Tavera *et al*. (1994), but remains Late Tithonian in age according to definition of this boundary adopted in the present paper (Figs 2, 3). The base of the NJK-d Subzone is designated by appearance of *N. steinmannii minor* in the uppermost part of the *Crassicollaria* Zone (Tavera *et al*., 1994). Tavera *et al*. (1994) placed this event in markedly lower stratigraphical position than originally Bralower *et al*. (1989) did.

Our results from the Sierra del Infierno indicate the presence of three nannoconid assemblages characterised as follows. The limestones occurring in the uppermost part of

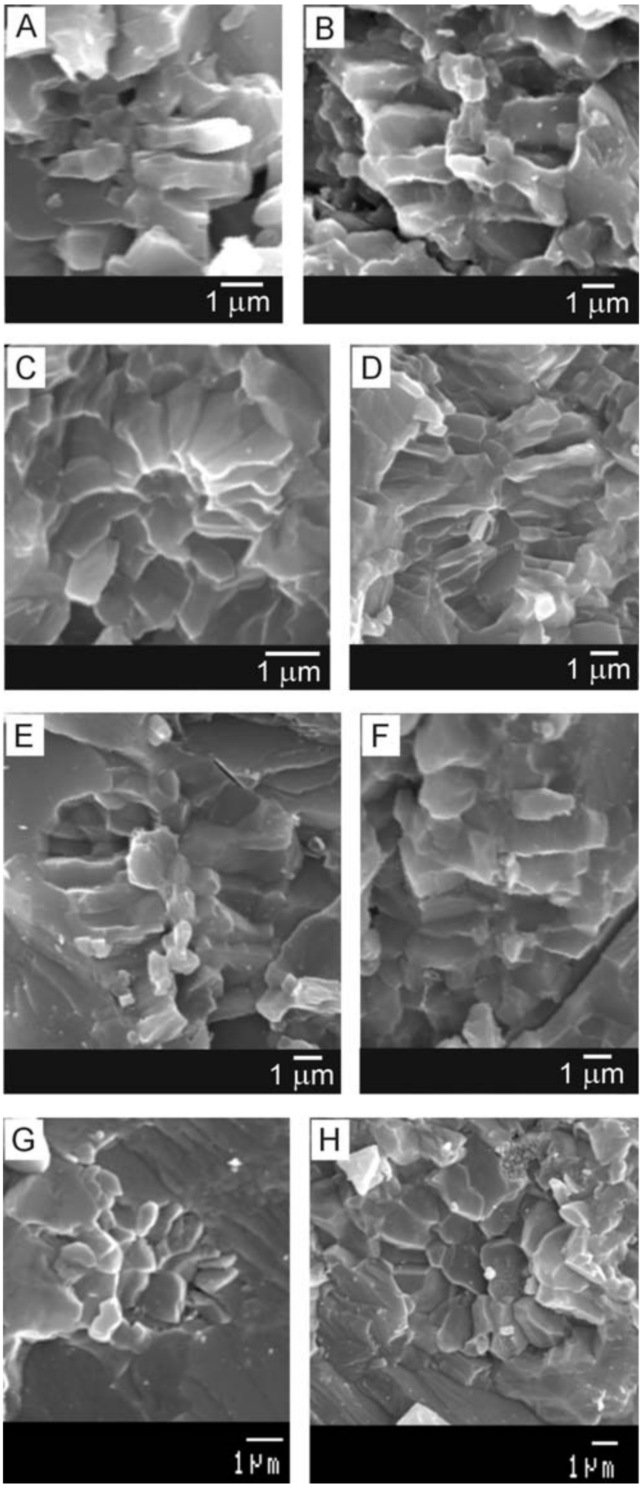

Fig. 9. SEM micrographs of nannoconids found in latest Tithonian–Early Berriasian limestones from the Sierra del Infierno sections, western Cuba (see Table 3). **A** – *Nannoconus* sp. aff. *N. infans* Bralower, sample PR01-1; **B** – *N. steinmannii minor* Deres & Achéritéguy, sample PR01-14; **C** – *N. wintereri* Bralower & Thierstein, sample PR06-1; **D** – *N.* cf. *wintereri* Bralower & Thierstein, sample PR06-1; **E** – *N. steinmannii minor* Deres & Achéritéguy, sample PR06-3; **F** – *N. steinmannii steinmannii* Kamptner, sample PR01-14; **G** – *N. infans* Bralower, sample PR06-15B; **H** – *N. globulus* Brönnimann subsp. *globulus* Bralower, Monechi & Thierstein, sample PR06-9

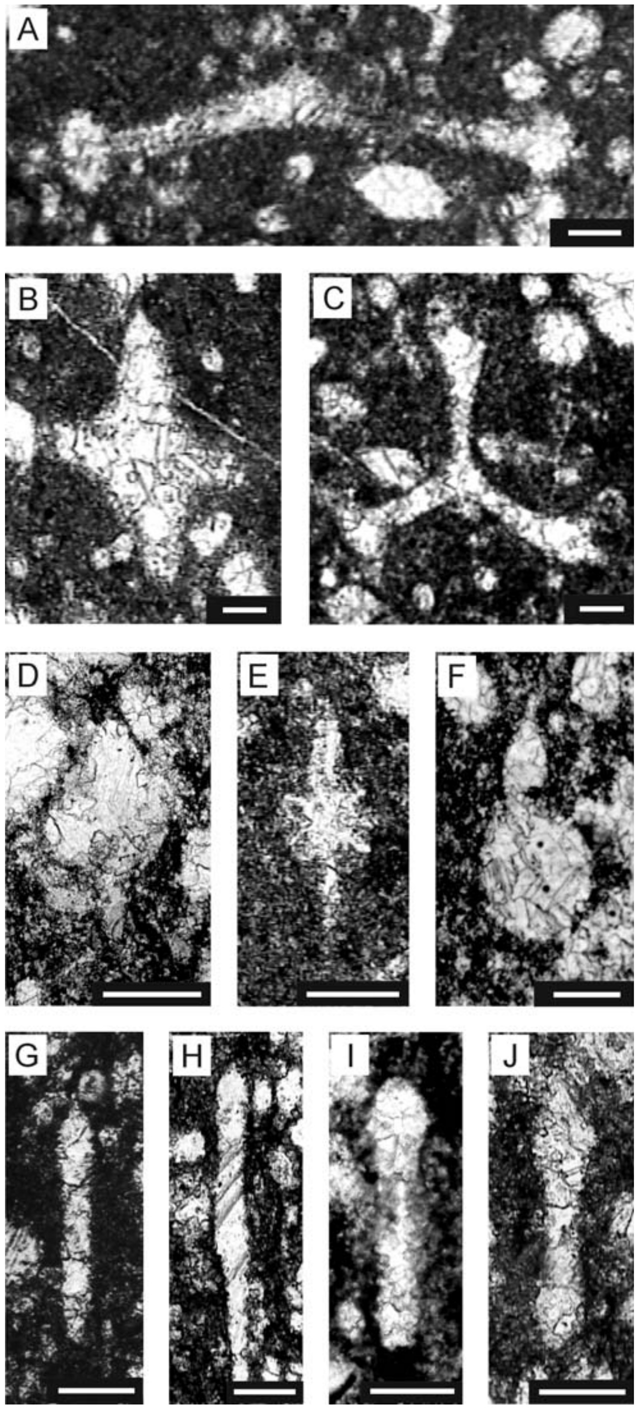

Fig. 10. Radiolarians identified in thin sections from studied limestone samples (Sierra del Infierno, western Cuba). **A** – *Tritrabs* sp. gr. *T. ewingi* s.l. (Pessagno), sample PR06-16B, latest Tithonian; **B** – *Higumastra* sp., sample PR06-1, latest Tithonian; **C** – *Tritrabs*? sp., sample PR06-16B, latest Tithonian; **D** – *Syringocapsa* sp., sample PR06-13B, latest Tithonian; **E** – *Pantanellium* sp. gr. *P. berriasianum* Baumgartner, sample PR06-1, latest Tithonian; **F** – *Sethocapsa* sp., sample PR06-6B, Early Berriasian; **G** – *Ristola* cf. *altissima altissima* (Rüst), sample PR06-1, latest Tithonian; **H** – *Ristola* sp., sample PR06-13B, latest Tithonian; **I** – *Ristola cretacea* (Baumgartner), sample PR06-8B, earliest Berriasian; **J** – *Bistarkum* sp. gr. *B. brevilatum* Jud, sample PR06-1, latest Tithonian. Scale bar = 100 µm

the El Americano Member belong to the Subzone named herein *Nannoconus wintereri* (Tab. 3; Figs 2, 3) and adopted after Tavera *et al*. (1994). We feel, however, that change of the original NJK-A to NJK-C Subzones for NJKa-c Subzones based on different nannofossils (cf. Bralower *et al*., 1989, Tavera *et al*., 1994) may cause confusion. Moreover, the boundaries of the subzones NJK-A to D and NJKa-d are also different. Therefore, we prefer the *Nannoconus wintereri* Subzone, instead of the NJK-c Subzone of Tavera *et al*. (1994). Our *N. wintereri* Subzone is latest Tithonian in age, although it may range to the earliest Berriasian. The shaded band marked between the *N. wintereri* and *N. steinmannii minor* subzones (Figs 2, 3) reflects lack of data for this interval in the studied sections. The base of our *N. wintereri* Subzone may correspond to the lower (but not basal) part of the Subzone NJK-C of Bralower *et al*. (1989). The nannoconid assemblages found in samples PR06-3 and PR06-10B (Tab. 3) correlate with the *N. steinmannii minor* Subzone (NJK-D) of Bralower *et al*. (1989). The base of our *N. steinmannii minor* Subzone could not be delineated with high precision, nevertheless, it is located probably within an interval, about 0.6 m, thick above the Tithonian–Berriasian boundary in the PR-06 section (Fig. 3). Nannoconids recorded in samples collected from the higher part of the studied sections match the limestones of the Tumbadero Member with the *N. steinmannii steinmannii* Zone (NK-1) of Bralower *et al*. (1989). Its lower boundary was correlated with the upper part of the *Calpionella alpina* Subzone and the middle to upper part of *Pseudosubplanites grandis* Zone (Bralower *et al*., 1989; Ogg *et al*., 1991; Bralower *et al*., 1995; Remane, 1997). In the Sierra del Infierno sections, the boundary between the *N. steinmannii minor* Subzone and *N. steinmannii steinmannii* Zone occurs within a rather wide interval because of lack of data (Figs 2, 3). The boundary of the El Americano and Tumbadero members occurs in the middle interval of the *N. steinmannii minor* Subzone.

RADIOLARIA

Calcitized radiolarians are common to abundant in the latest Tithonian and Early Berriasian limestones of the Sierra del Infierno. Only few specimens in a particular thin section could be identified being relatively better preserved (Fig. 10: A–J). Radiolarians from the PR-06 section (Fig. 11) comprise *Bistarkum* sp. gr. *B. brevilatum* Jud (Fig. 10J), *Higumastra* sp. (Fig. 10B), *Pantanellium* sp. gr. *P. berriasianum* Baumgartner Fig. 10E), *Pseudoeucyrtis*? sp., *Ristola cretacea* (Baumgartner) (Fig.10I), *R.* cf. *altissima altissima* (Rüst) (Fig. 10G), *Ristola* sp. (Fig. 10H), *Sethocapsa* sp. (Fig. 10F), *Syringocapsa* sp. (Fig. 10D), *Tritrabs* sp. gr. *T. ewingi* s. l. (Pessagno) (Fig. 10A), *Tritrabs*? sp. (Fig.

SUBSTAGE	*Calpionellid subzones*	Sample	Radiolarian taxa																							
			Archaeospongoprunum? sp.	*Bistarkum* sp. gr. *B. brevilatum*	*Higumastra* sp.	*Mirifusus* gr. *apenninicus*	*Mirifusus* gr. *dianae* s. l.	*Mirifusus* cf. *dianae minor*	*Neoparonaella* sp. gr. *N. volatica*	*Pantanellium* sp. gr. *P. berriasianum*	*Pantanellium* sp.	*Paronaella* gr. *pristidentata*	*Pseudoeucyrtis*? sp.	*Ristola* cf. *altissima altissima*	*Ristola cretacea*	*Ristola* cf. *cretacea*	*Ristola* sp.	*Sethocapsa* sp. gr. *S. kitoi-zweilii*	*Sethocapsa* sp.	*Spongocapsula* sp. gr. *S. obesa*	*Spongocapsula* sp.	*Spongotripus*? sp.	*Syringocapsa* sp.	*Transhsuum* sp.	*Tritrabs* sp. gr. *T. ewingi* s. l.	*Tritrabs*? sp.
LOWER BERRIASIAN	*C. alpina*																									
		PR01-12																						■		
		PR06-16					■						■							■	■					
		PR06-13				■															■					
		PR01-7																■	■							
		PR06-9															■									
		PR06-8									■	■										■				
		PR06-7	■										■				■									
		PR06-3B				■									■											
		PR06-3/6B		■				■								■	■		■							
		PR06-8B						■					■		■		■									
UPPER TITHONIAN	*Cr. intermedia*																									
		PR06-13B															■						■			
		PR06-1		■	■					■	■		■	■			■									
		PR06-15B				■																				
		PR06-16B		■					■								■								■	■

Fig. 11. Selected radiolarian taxa identified in thin sections from the latest Tithonian–Early Berriasian limestones of Sierra del Infierno, western Cuba (not to scale)

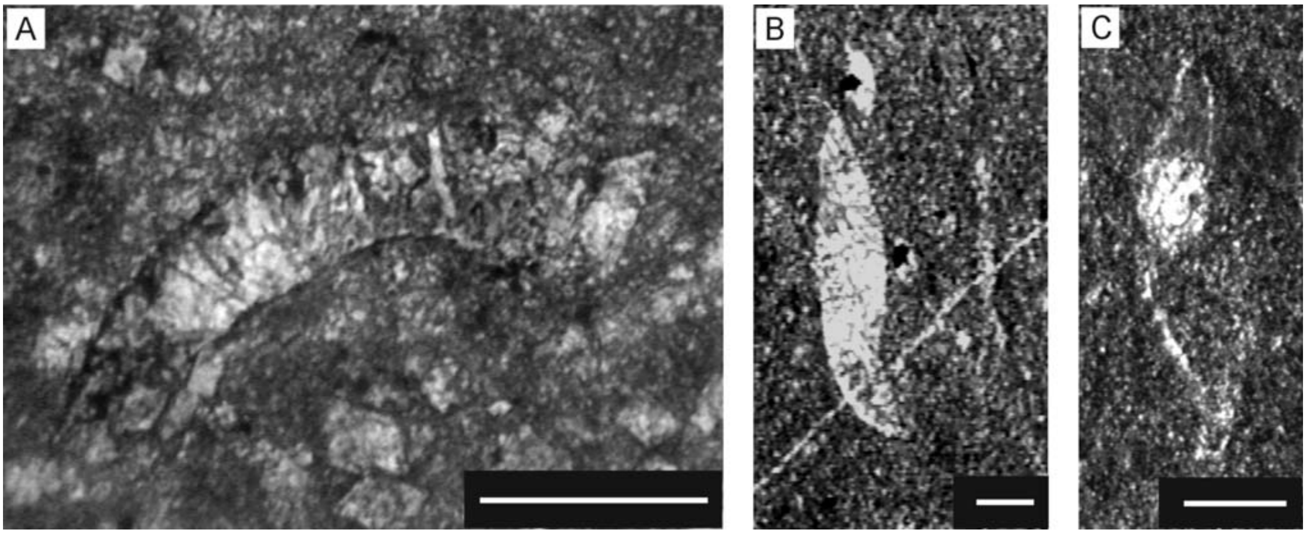

Fig. 12. Juvenile ammonites and benthic crinoid identified in thin sections. **A** – *Protancyloceras* gr. *hondense* (Imlay), sample PR06-5, Early Berriasian; **B** – *Vinalesites* sp., sample PR01-05, earliest Berriasian; **C** – Phyllocrinidae, gen. et sp. indet., sample PR01-5, earliest Berriasian. Scale bar = 100 μm

10C), and other taxa. These Radiolaria are consistent with the latest Tithonian–Early Berriasian age of the studied limestones and correspond to the lower part of D2 radiolarian zone recognized by Jud (1994) for the Maiolica Formation of the Western Tethys. Only *Ristola altissima altissima* (Rüst) was reported from the Bathonian–early late Tithonian (Baumgartner *et al*., 1995a). However, *R. altissima* (Rüst) was used as marker taxon to define a Late Tithonian to Berriasian 4α Subzone of radiolarian biozonation in the western North America (Hull, 1997). Pessagno *et al*. (1999) correlated the uppermost part of the El Americano Member and the Tumbadero Member with the 4α Subzone, although taxa from the above-mentioned stratigraphical interval of these Cuban units have not been specified.

Radiolarians identified as *Bistarkum* sp. gr. *B. brevilatum* Jud are compared with taxon, which appeared in the latest Tithonian (Baumgartner *et al*., 1995a). A specimen identified as *Sethocapsa* sp. gr. *S. kitoi-zweilii* (sample PR01-7, Fig. 11) is related to taxa known to appear in the latest Tithonian and Early Berriasian, respectively (Baumgartner *et al*., 1995a). The radiolarians from the genera *Ristola* Pessagno & Whalen *sensu* Baumgartner (Fig. 10G-I) and *Mirifusus* Pessagno emend. Baumgartner seem to be relatively frequent in the studied limestones (Fig. 11), whereas representatives of *Syringocapsa* sp. and *Pantanellium* Pessagno could be seldom identified in our thin sections.

JUVENILE UNCOILED AMMONITES

As mentioned above, no macrofossils were found during sampling of the studied sections. However, juvenile ammonites do occur in some thin sections (Fig. 12A, B; Tab. 4). A juvenile ammonite from sample PR06-5 (Fig. 12A), identified by Dr. R. Myczyński (personal information, 2004) as *Protancyloceras* gr. *hondense* (Imlay) is Early Berriasian in age. A juvenile specimen of *Vinalesites* sp. (Fig. 12B) was found in thin section made from the limestone of earliest Berriasian age (sample PR01-5). Fragments of *Vinalesites* sp. were also recognised in thin sections from the PR01-1 and PR01-4 samples (latest Tithonian and earliest Berriasian, respectively); in the former sample, a juvenile *Protancyloceras* sp. was also identified (Tab. 4).

These findings add new information concerning the ammonite occurrences around the Tithonian–Berriasian boundary in the Sierra de los Organos. The juvenile ammonite assemblage *Protancyloceras* – *Vinalesites* refers to the *Protancyloceras hondense* – *Vinalesites rosariensis* Acme Zone proposed by Myczyński (1989), and Myczyński and Pszczółkowski (1990). We conclude that the *Protancyloceras* - *Vinalesites* assemblage crosses the *Crassicollaria/Calpionella* zones boundary in the Sierra del Infierno sections (Tab. 5). The last occurrence of this ammonite assemblage is situated in the basal part of the Tumbadero Member (cf. Myczyński & Pszczółkowski, 1990). Nevertheless, rare uncoiled juvenile ammonites (?*Protancyloceras* sp.) occur also in the upper part of the Tumbadero Member of Late Berriasian age (Pszczółkowski & Myczyński, 2004).

Table 4

Juvenile ammonites found in thin sections (Sierra del Infierno, western Cuba)

Section	Sample	Taxa	Calpionellid subzone	Age
PR-06	PR06-5	*Protancyloceras* gr. *hondense* (Imlay)	*C. alpina*	Early Berriasian
PR-01	PR01-5	*Vinalesites* sp.	*C. alpina*	earliest Berriasian
	PR01-4	?*Vinalesites* sp.		
	PR01-1	*Vinalesites* sp. *Protancyloceras* sp.	*Cr. intermedia*	latest Tithonian

Table 5

Correlation of microfossil, *Nannoconus* and ammonite zones recognized in the Sierra del Infierno sections (not to scale)

<table>
<tr><th>Age</th><th colspan="2">Calpionellid zonation (Remane et al.,1986)</th><th colspan="2">Nannoconus Zone and Subzones (after Bralower et al., 1989, and Tavera et al., 1994, modified)</th><th>Radiolarian zone (Jud, 1994)</th><th>Ammonite assemblage</th><th>Members</th></tr>
<tr><td rowspan="3">Early Berriasian</td><td rowspan="3">Calpionella</td><td rowspan="3">Calpionella alpina</td><td colspan="2">(?)</td><td rowspan="4">D2</td><td rowspan="2">(?)</td><td rowspan="2">Tumbadero (lower part)</td></tr>
<tr><td colspan="2">N. steinmannii steinmannii Zone ?</td></tr>
<tr><td rowspan="2">NJK</td><td>Nannoconus steinmannii minor Subzone</td><td rowspan="2">Protancyloceras - - Vinalesites</td><td rowspan="2">El Americano (uppermost part)</td></tr>
<tr><td>latest Tithonian</td><td>Crassicollaria</td><td>Cr. intermedia</td><td>Nannoconus wintereri Subzone</td></tr>
</table>

REMARKS ON SEDIMENTARY ENVIRONMENT

The Late Tithonian limestones of the El Americano Member (upper part) were deposited in an outer neritic to bathyal environment. The radiolarian and calpionellid biomicrites with chert interbeds of the Tumbadero Member represent bathyal deposits laid down below the aragonite compensation depth – ACD (Pszczółkowski, 1999). The results of our work reveal some additional features of the sedimentary environment in the studied stratigraphic interval. The Tumbadero Member differs from the El Americano Member by: (1) presence of black chert interbeds, and (2) scarcity of macrofauna. The first feature is a manifestation of increased radiolarian productivity during Early Berriasian time. Recurring presence of the calpionellid-*Globochaete* microfacies between the radiolarian biomicrites is a distinctive feature of the studied limestones. In the Upper Jurassic–Lower Cretaceous Maiolica succession of Hungary, rhythmic variations in the quantity of radiolarians and calpionellids were explained by orbitally induced climatic changes (Haas *et al*., 1994; see also Reháková & Michalík, 1994 as concerns the coeval sections in Slovakia). The scarcity of macrofauna in the investigated west Cuban limestones resulted from deposition below ACD and poor oxygenation of the bottom waters. Dark-grey to black colour, preserved lamination (Fig. 6B), and disseminated framboidal pyrite are common in the investigated succession of biomicrites with thin interbeds of calcareous shales. Paucity of benthic macrofossils is conspicuous. A single specimen of juvenile crinoid (Fig. 12C) was found within the considered stratigraphic interval, and very scarce bioclasts of shelly fauna (bivalves?) were observed in thin sections (Fig. 5B). The above-mentioned crinoid specimen belongs to the family Phyllocrinidae Jaekel, 1907 (cf. Arendt, 1974). Representatives of this family were adapted to nearly stagnant environment (Głuchowski, 1987); however, echinoderm debris is uncommon in the microfacies types recognized in the Sierra del Infierno sections. The studied deposits are seldom bioturbated, although presence of pelmicrosparites in the limestones of the Tumbadero Member (Fig. 5B) may support occasional activity of benthic invertebrates during Early Berriasian time. Thus, the discussed latest Tithonian–Early Berriasian deposits have probably been accumulated in the dysaerobic zone (*sensu* Byers, 1977).

Dark-grey to black thin-bedded radiolarian biomicrites are also characteristic for the Late Tithonian–Early Berriasian deposits of the Northern Rosario and Placetas belts of western and central Cuba (Myczyński & Pszczółkowski, 1994; Pszczółkowski & Myczyński, 2004). Around the Jurassic–Cretaceous boundary dysaerobic (to anaerobic?) conditions at the sediment/seawater interface could be widespread in the northwestern part of the Proto-Caribbean basin. Such conditions reflected rather sluggish circulation in that part of relatively narrow Proto-Caribbean seaway in its deeper waters. This may be a likely explanation, why the west Cuban pelagic limestones of the latest Tithonian–Early Berriasian age and coeval Maiolica (or Biancone) limestones of Tethyan successions in Europe (Wieczorek, 1988; Jud, 1994) are dissimilar.

CONCLUSIONS

1. In the Sierra del Infierno sections (Sierra de los Organos, western Cuba), the limestones of the uppermost part

of the El Americano Member (Guasasa Formation) belong to the Late Tithonian *Crassicollaria intermedia* Subzone of the *Crassicollaria* Standard Zone, and to the basal part of the *Calpionella alpina* Subzone (Early Berriasian). The lower part of the Tumbadero Member is assigned to the *C. alpina* Subzone of the *Calpionella* Standard Zone.

2. The radiolarian taxa identified in thin sections are consistent with the lower part of D2 radiolarian zone of Jud (1994).

3. The studied limestones belong to the *Nannoconus wintereri* Subzone, *N. steinmannii minor* Subzone and *N. steinmannii steinmannii* Zone (Tab. 3). The boundary of the El Americano and Tumbadero members occurs in the *N. steinmannii minor* Subzone.

4. A heteromorph ammonite assemblage (*Protancyloceras - Vinalesites*), represented by few juvenile specimens only, crosses the *Crassicollaria/Calpionella* zones boundary in the studied sections.

5. The radiolarian and radiolarian-calpionellid microfacies are characteristic for the limestones of the uppermost part of the El Americano Member and the lower part of the Tumbadero Member.

6. The investigated deposits of latest Tithonian and Early Berriasian age probably accumulated in the dysaerobic zone. At that time, dysaerobic to anaerobic conditions could be widespread in the deeper waters reflecting rather sluggish circulation in the northwestern part of the Proto-Caribbean basin.

Acknowledgements

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Streszczenie

STRATYGRAFIA KALPIONELLIDOWA I NANNOKONUSOWA ORAZ MIKROFACJE WAPIENI WYSTĘPUJĄCYCH W POBLIŻU GRANICY TYTON–BERIAS W SIERRA DEL INFIERNO (ZACHODNIA KUBA)

Andrzej Pszczółkowski, Dora García Delgado & Santa Gil González

W niniejszej pracy zostały zbadane dwa profile obejmujące wapienie najwyższego tytonu i dolnego beriasu w Sierra del Infierno, na zachód od Viñales w zachodniej części Kuby (Fig. 1A–C). Wapienie najwyższej części ogniwa El Americano formacji Guasasa (Tab. 1) należą do podpoziomu *Crassicollaria intermedia* poziomu standardowego *Crassicollaria* (górny tyton) i najniższej części podpoziomu *Calpionella alpina* (dolny berias) poziomu standardowego *Calpionella* (Fig. 2, 3). Dolna część ogniwa Tumbadero została zaliczona do podpoziomu *C. alpina*. W wapieniach najwyższej części ogniwa El Americano (Fig. 4A) i dolnej części ogniwa Tumbadero (Fig. 4B) charakterystyczne są mikrofacje kalpionellidowa (Fig. 5A) i radiolariowa (Fig. 6A). Pelmikrosparyty (Fig. 5B) i laminowane biomikryty (Fig. 6B) również są spotykane w dolnym beriasie.

Kalpionellidy (Fig. 7A–I) są reprezentowane przez pojedyncze okazy do bardzo licznych zespołów (Tab. 2); zwykle są one słabo zachowane. Jest to już wcześniej opisana cecha kalpionellidów obecnych w wapieniach późnego tytonu i beriasu sukcesji Sierra de los Organos (Pop, 1976). Badane wapienie zawierają również nannokonidy (Fig. 8, 9A–H) zaliczone tutaj do podpoziomów *Nannoconus wintereri* i *N. steinmannii minor* oraz do poziomu *N. steinmannii steinmannii* (Tab. 3). Granica ogniw El Americano i Tumbadero znajduje się w obrębie podpoziomu *N. steinmannii minor*. Radiolarie oznaczone w płytkach cienkich

(Fig. 10A–J, 11) odpowiadają dolnej części poziomu radiolariowego D2 ustalonego w formacji Maiolica zachodniej Tetydy (Jud, 1994). Niektóre rodzaje (*Ristola*, *Mirifusus*) są często spotykane w badanych profilach.

Obecność juwenilnych amonitów rozwiniętych: *Protancyloceras* gr. *hondense* (Imlay) (Fig. 12A), *Protancyloceras* sp. i *Vinalesites* sp. (Fig. 12B) została stwierdzona w niektórych płytkach cienkich wykonanych z wapieni (Tab. 4). Zespół tych amonitów przekracza granicę poziomów kalpionellidowych *Crassicollaria* i Calpionella (Tab. 5). Szare, ciemnoszare i czarne wapienie najwyższej części ogniwa El Americano i dolnej części ogniwa Tumbadero zostały osadzone prawdopodobnie w strefie dysaerobowej, w której fauna bentosowa była bardzo nieliczna (Fig. 12C). Ławice wapieni zazwyczaj nie zawierają struktur wskazujących na intensywną działalność organizmów ryjących w osadzie. W pobliżu granicy tytonu i beriasu (J/K), warunki dysaerobowe (lub nawet anaerobowe) mogły być rozprzestrzenione w głębszych wodach północno-zachodniej części basenu Protokaraibskiego. Takie warunki wskazują na raczej słabą cyrkulację w głębszych wodach tego dosyć wąskiego w tym czasie basenu.